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ABSTRACT

This paper describes new reinforced thermoplastic materials that have been developed for rigid exterior, painted automobile panels. Traditionally these panels have been fabricated from zinc die cast, steel, or more recently from sheet molding compound (SMC). Guide Lamp Division of General Motors is injection molding mineral filled nylon, fiber glass reinforced nylon, and fiber glass reinforced thermoplastic polyester rigid exterior automotive panels that are painted car color for 1974 Chevelles, Cadillacs, Pontiacs, Oldsmobiles and Buicks. The applications, material properties, paint performance, and design recommendations for these three reinforced thermoplastic materials are reviewed.

MATERIAL AND DESIGN GUIDELINES FOR REINFORCED THERMOPLASTIC BODY PANELS

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Guide Lamp Division of General Motors has produced exterior automotive panels and fender extensions that are painted car color from die cast zinc, sheet molding compound, or bulk molding compound (polyester premix) for several years. A program was begun in 1964 at Guide Lamp to develop injection molded thermoplastics for these types of applications, with initial concentration primarily on nylon and acetal materials. The program concentration shifted in 1969 to fiber glass reinforced and mineral-filled nylons. The study of fiber glass reinforced thermoplastic polyesters for these applications was also begun in 1972. A number of experimental tools were built for application development, and thousands of parts were molded and tested. Some of the different types of experimental parts are included in Figure 1.

Laboratory and service testing indicated that fiber glass reinforced nylon, mineral-filled nylon, and fiber glass reinforced thermoplastic polyester each have properties and characteristics similar to sheet molding compound (SMC) and bulk molding compound (BMC), materials previously used for exterior automotive panels. These reinforced thermoplastic materials were introduced for the first time as exterior, car color body panel materials for the 1973 and 1974 car models. Guide Lamp has been a major producer of reinforced thermoplastic automotive components for the past several years--using over 13 million pounds of reinforced thermoplastics per year for lamp housings, consoles, instrument panel inserts, and fan shrouds. This extensive engineering and production background and experience with reinforced thermoplastics was important and essential to the successful introduction of these major, new body applications.

Fiberglass filled nylon was used as a painted exterior body panel material for the first time for the 1973 Oldsmobile Omega rear panel as pictured in Figure 2. Mineral filled nylon was used as a painted exterior body panel material for the first time for the 1973-1/2 and 1974 Buick Apollo rear panel and

rear fender extensions (Figure 2). Fiberglass reinforced thermoplastic polyester was used for painted exterior rear body panels for the first time in the 1974 Pontiac LeMans and Catalina-Bonneville rear license pocket panels and the 1974 Chevelle-Laguna rear panel (Figure 3). The replacement of die cast metals and steel in exterior body panels by these engineering reinforced thermoplastics has been due to a combination of the following properties--ease of processing, limited finishing steps, reduction of component parts, cost reduction, weight reduction, and broad styling capabilities.

Reinforced nylon and thermoplastic polyester materials will be reviewed in this paper in terms of their physical properties, applications, design criteria, and paintability for exterior body panels.

MATERIALS AND APPLICATIONS

A. MATERIAL PROPERTY REQUIREMENTS

The following property requirements are necessary for plastic materials for painted exterior body panels:

High tensile strength - Hold fasteners, withstand assembly handling, support other components such as lenses and lamp bezels.

High flexural strength - Must withstand severe flexing in assembly and across-car torsional flexing and impacts in service. Parts must bend and conform to mating sheet metal.

Good impact - Must withstand assembly, rock impacts, field abuse.

High heat distortion - Must withstand oven temperatures of up to 350°F for curing and reflowing exterior acrylic lacquers without part distortion.

High rigidity - Must be able to support self and components without distortion. Must not distort in paint bake ovens up to 350°F.

Good surface finish - Must have good surface without defects as molded, minimal sinks opposite bosses or ribs on appearance surfaces.

Good paint adhesion - Excellent paint adhesion must not exude internal lubricants to the surface that could affect the paint.

B. COMPARATIVE PROPERTIES OF EXTERIOR BODY PANEL MATERIALS

The mechanical properties of zinc die cast, polyester premix or bulk molding compound, mineral filled nylon, fiberglass reinforced nylon, and fiberglass reinforced thermoplastic polyester are listed in Table 1. All of these materials are being used for car color painted exterior body panels. Zinc die cast is much stronger and more rigid than any of the engineering plastics. However, the mineral filled nylon, glass filled nylon, and thermoplastic polyesters have been proven by extensive testing to have adequate properties for exterior body panels and surpass other exterior body materials in many ways. The reinforced thermoplastics are more flexible and ductile than other body panel materials and bend to conform to mating sheet metal. Flash free, defect free parts are injection molded that require no trimming or repair. These materials permit fast molding cycles and automatic machine operation. They are lower cost than other body panel approaches, particularly in

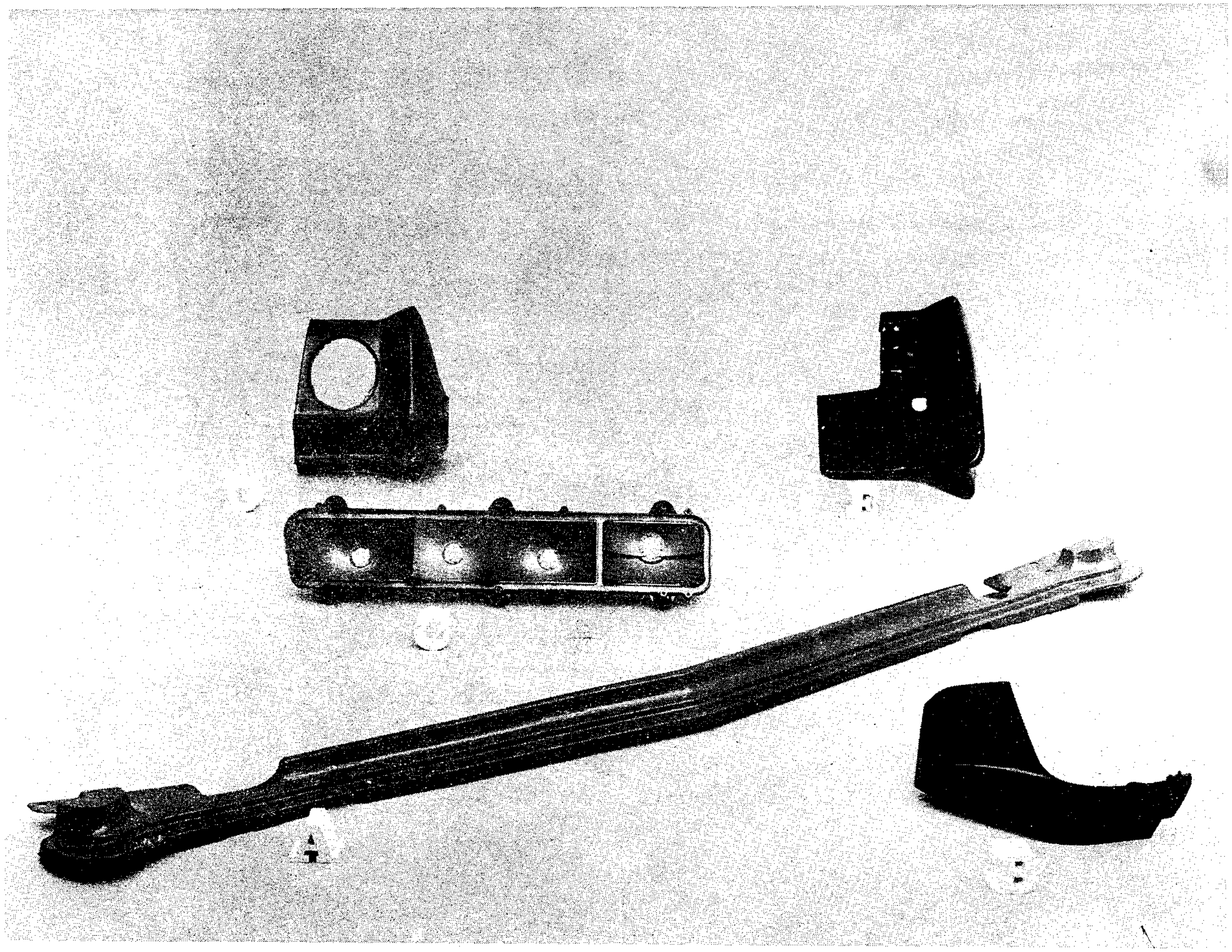

FIG. 1 - Experimental Reinforced **Thermoplastic** Body Panel Parts. These five and other experimental parts were thoroughly tested and evaluated before materials approval for production application: (A) 1968 Chevrolet Nova front bumper filler panel, (B) 1973 Oldsmobile "88" rear fender extension, (C) 1970 Buick Electria tail lamp housing, (D) 1968 Chevrolet Impala rear fender extension, (E) 1965 Pontiac Tempest rear fender extension.

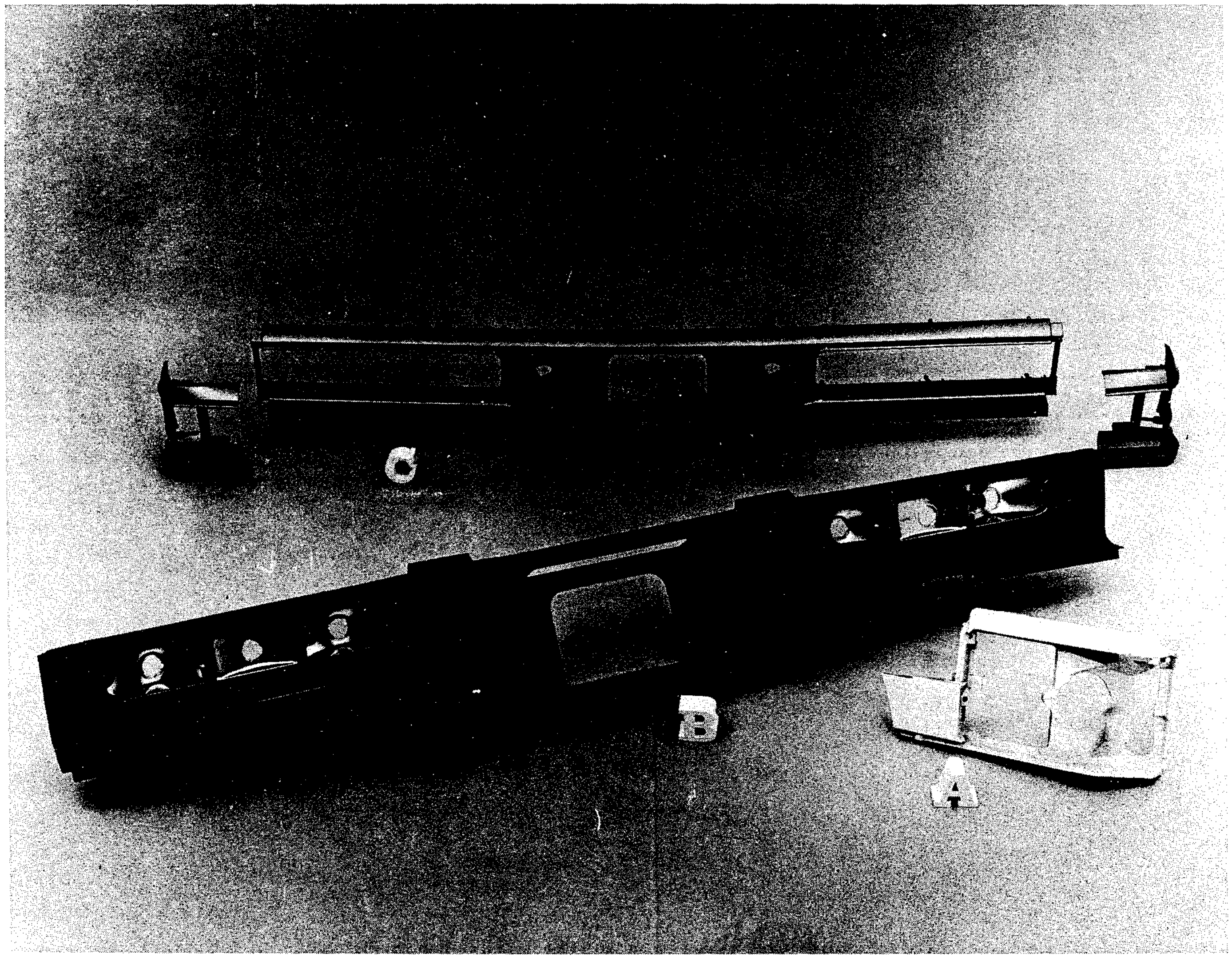

FIG. 2 - Reinforced Nylon Production Body Panels. (A) 1974 Cadillac front fender extension (mineral filled nylon), (B) 1973-1974 Oldsmobile Omega rear panel (glass filled nylon), (C) 1973-1/2-1974 Buick Apollo rear panel and fender extensions (mineral filled nylon).

larger, more complicated parts. The thermoplastic materials do not corrode. Part weights with these materials are reduced by 60 per cent versus zinc die cast and 20 per cent versus bulk molding compound or sheet molding compound. These attributes made these engineering thermoplastics important and definitely advantageous over other body panel materials.

the 1973-1974 Oldsmobile Omega rear applique panel (Figure 2). As can be seen from Table 1, this material has excellent tensile and flexural strengths as compared to bulk molding compound. Bulk molding compound has been used for painted exterior fender extensions and headlamp housings in previous production years. Reinforced nylon has excellent rigidity and good re-

TABLE 1 - Comparative Mechanical Properties of Exterior Body Panel Materials

Mechanical Property	Test Method	Zinc Die Cast SAE 903	Bulk Molding Compound or Polyester Pre-mix	Mineral Filled Nylon	Glass Filled Nylon	Glass Filled Thermoplastic Polyester
Tensile strength (Psi)	ASTM-D688-64 (2)	41,000	5,000	11,000	11,000	17,000
Flexural strength (Psi)	ASTM-D790-66 (2)	---	12,000	22,000	20,000	27,000
Flexural Modulus (Psi)	ASTM-D790-66 (2)	10,000,000	1,000,000	750,000	790,000	1,200,000
Unnotched Izod Impact Ft. lb./in., +75°F	ASTM-D256-56 (2)	43 ft.-lb. (Charpy)	4-6	20	4	15
Heat Distortion Temp., °F, 66 Psi	ASTM-D648-56 (2)	Over 500°F	400°F	275°F	370°F	420°F
Specific Gravity	ASTM-D-792	6.6	1.8	1.47	1.25	1.52
Fiber Content-%		---	20% (fiber-glass)	40% (mineral)	15% (fiber-glass)	30% (fiber-glass)
Material Cost-Cents/cubic inch		7.85	1.68	3.70	2.25	3.85

C. FIBERGLASS FILLED NYLON

Fiberglass reinforced nylon 6 was the first reinforced thermoplastic material to be used for a painted exterior automobile body panel--

sistance to part distortion at up to 350°F. Its impact performance is good in the dry state and excellent after absorbing moisture. Nylons develop more ductility or flexibility and toughness as they absorb moisture--a phenomenon

that occurs in part service. In the dry-as-molded state, glass reinforced nylon is somewhat notch sensitive or will break in sharp corner areas. Proper part design can alleviate notched conditions. Part length is not significantly affected by moisture absorption. Appearance sinks opposite mounting bosses can also be a problem. This is not a problem in the Omega rear panel because all mounting bosses are designed opposite non-appearance surfaces. This is the lowest cost material of the three reinforced thermoplastic materials reviewed.

D. MINERAL FILLED NYLON

Guide Lamp is injection molding mineral filled nylon in three applications for 1974: (1) 1974 Cadillac Calais, Brougham, DeVille front fender extensions, (2) 1973-1/2, 1974 Buick Apollo rear panel, and (3) 1973-1/2, 1974 Apollo rear fender extensions (Figure 2). The 1973-1/2 Apollo applications were the first exterior automotive applications of mineral filled nylon.

This engineering thermoplastic was chosen for the Cadillac front fender extensions and the Buick components because it exhibits, as shown in Table 1, high tensile strength, high rigidity, high unnotched impact strength, and adequate heat distortion resistance. Although its heat distortion in Table 1 is listed as 275°F, this material will pass through paint reflow oven temperatures of up to 350.F without distortion, if processed without stress and supported properly. A further consideration for having chosen this material was its ductility and flexibility. This material has the least sink opposite mounting bosses or appearance surfaces of the three materials reviewed in this paper, as indicated in Table 2. It also has the least warpage tendency in molded parts of the three materials discussed. These are the reasons that it was selected for the current 1974 production applications.

The main limitation in using mineral filled nylon is its notch sensitivity--or tendency to break at sharp corners in the dry, as molded state. Mineral filled nylon also absorbs water and becomes more flexible. These factors should be considered in part design.

TABLE 2 - Sink Measurement Opposite A Mounting Boss of Various Body Panel Materials

Materials	Sink Depth (Mils)
1. 40% mineral filled nylon	4.2
2. 15% glass filled nylon	17.0
3. 30% glass filled thermoplastic polyester	13.5
4. 30% glass filled nylon	11.5

Readings were made on a precision "contour reader" on a 20X magnification. The boss size was for a 1/4-20 fastener.

E. FIBERGLASS FILLED THERMOPLASTIC POLYESTER

Guide Lamp is injection molding three exterior rear panels in 1974 from fiberglass filled thermoplastic polyester: (1) 1974 Pontiac LeMans rear license panel, (2) 1974 Pontiac Catalina-Bonneville rear license panel, and (3) 1974 Chevrolet Laguna rear body panel (two pieces)(Figure 3).

The reinforced thermoplastic polyester material is the strongest, most rigid and highest heat resistant of the plastic materials listed in Table 1. It is not affected by moisture, as is nylon. It is, therefore, the best of the materials being considered in structural strength and is also the most costly. Problems can exist with appearance sinks opposite mounting bosses and part warpage as molded, if the part and tool are not properly designed.

DESIGN CRITERIA

The reinforced nylons and thermoplastic

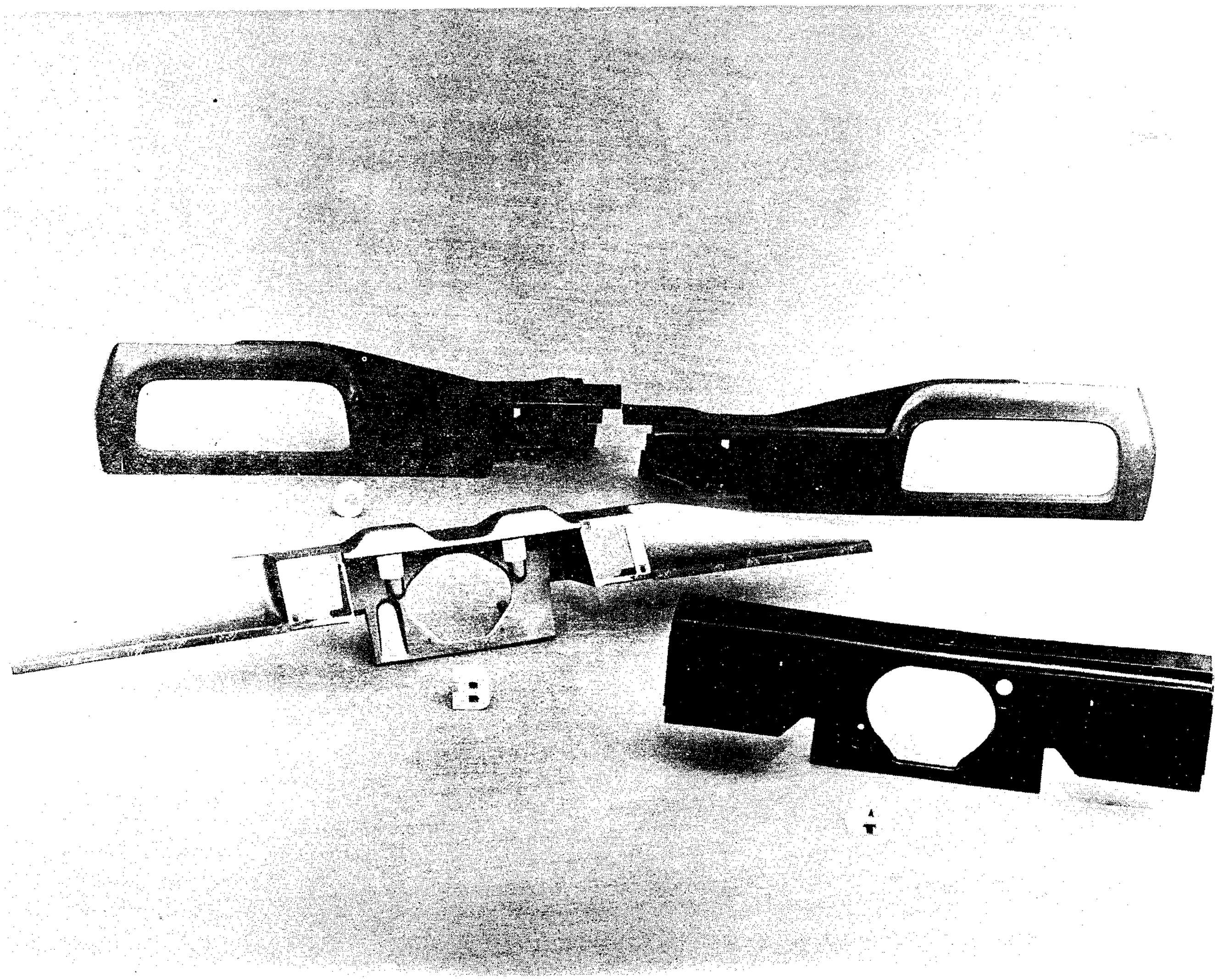

FIG. 3 - Fiberglass Filled Thermoplastic Polyester Production Body Panels. (A) 1974 Pontiac Catalina-Bonneville rear license panel, (B) 1974 Pontiac LeMans rear license panel, (C) 1974 Chevrolet Chevelle-Laguna rear panel.

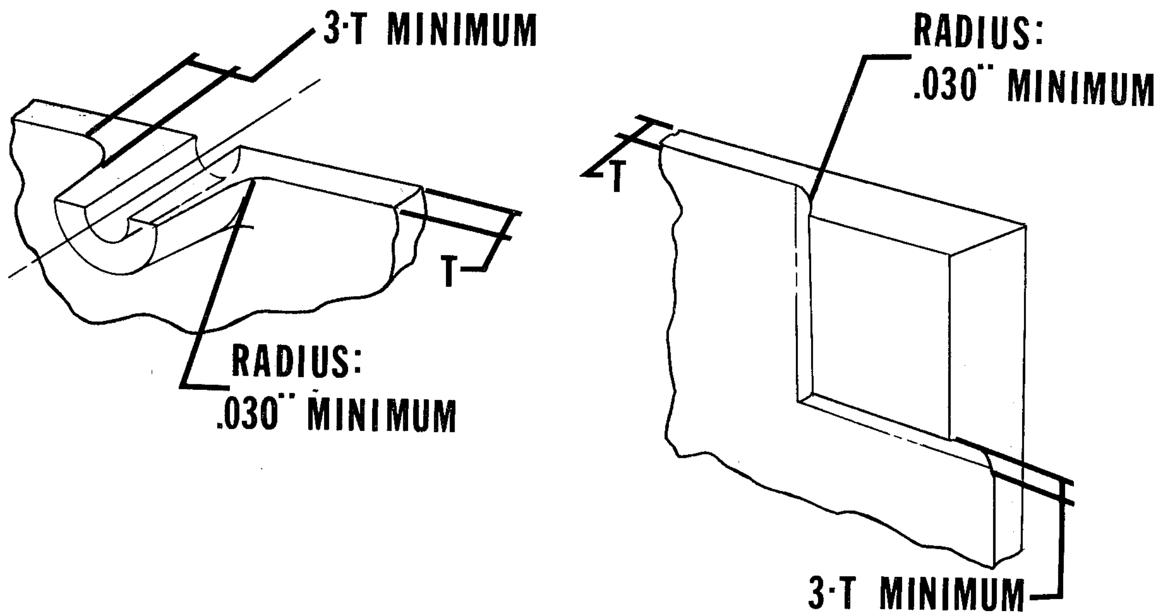

FIG. 4 - Transition Area Geometry for (A) wall thickness changes and (B) boss areas. A gradual transition length of three times the wall thickness should be used with a minimum radii of .030".

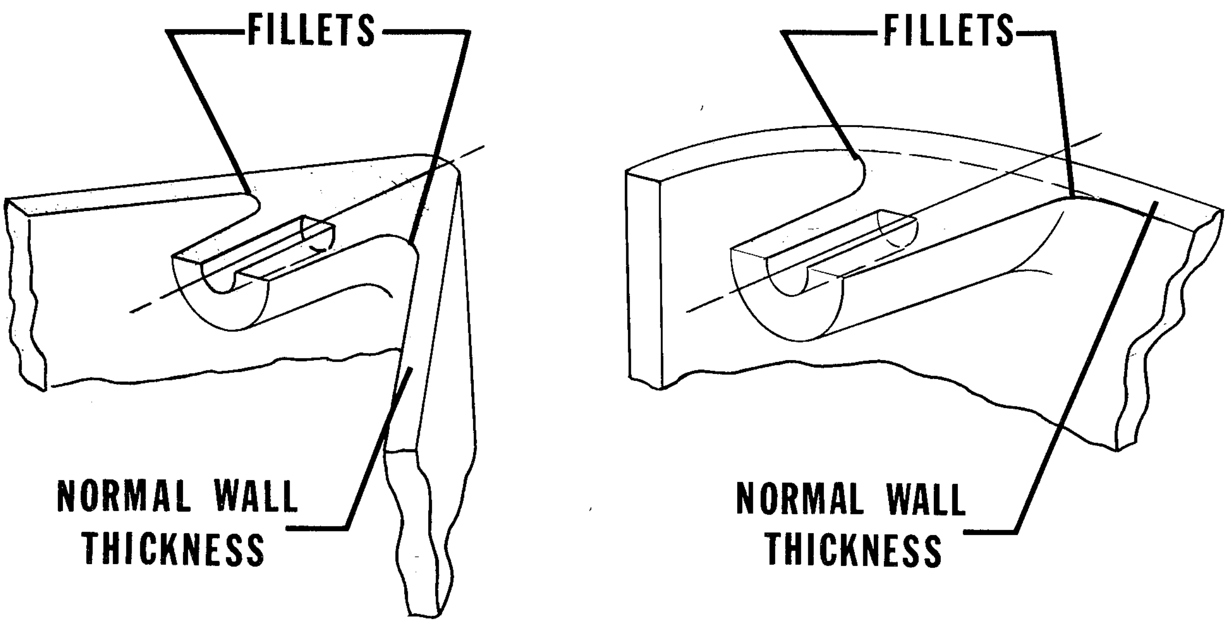

FIG. 5 - Design locations to help minimize sinks opposite bosses. Bosses should be located opposite the apex of angles where the surface changes abruptly.

polyesters have proven their practicability in existing automotive applications. Each material offers unique combinations of properties to give the essential performance requirements needed in automotive body panel applications. The design engineer should be familiar with these combinations of properties in order to select the best material for a specific application. In this way, he can produce a high quality part at minimum cost. The most important factors in designing plastic body panels are wall thickness, ribs, radii and fillets, bosses and studs, attachments, and design for minimum warpage. These will be discussed in detail.

Wall thickness for automotive body panels should be kept uniform and as thin as is possible as dictated by the requirements of the part. A nominal wall thickness of .090"-.110" is most desirable for use with the filled nylons and thermoplastic polyesters. Thicknesses below .050-.060 inch are difficult to fill in molding. Where changes in wall thickness are required by part design, a gradual transition should be used between thick and thin sections, as shown in Figure 4.

Ribs are designed into automotive body panels to strengthen parts without an increase in wall thickness. This provides additional strength and rigidity with minimal increase in weight and cost. Ribs may be added to prevent part warpage. Rib thickness should be limited to a maximum of 50% of the wall thickness of the adjacent wall because thicker ribs will cause sink marks on appearance surfaces of body panels. Nominal wall thickness may have to be locally increased in the rib areas to minimize sinks. A .010"-.020" radius should be located at the intersection of the rib and the adjacent wall. Ribs should conform to exterior surface contour and rib height should be as short as possible. A 1° draft angle should be used for all ribs so that they will release from the die.

Filled nylons and thermoplastic polyester resins are notch sensitive materials. These materials, under high stress conditions, will fail or break first in sharp corners or notched areas. Sharp corners in part should be eliminated by use of radii and fillets. Internal corners should have fillets of .025" to .075" and external corners should have radii of .015" to .040" which are adequate for most body panel applications. This will reduce the effect of stress concentrations at sharp corners.

Minimal sinks opposite bosses will result with the correct design of parts with filled nylon or thermoplastic polyesters. In general, the boss height should not be more than twice the boss diameter. A generous radius or fillet should be provided where the boss joins the wall section. The bosses should be located at the apex of angles where the surface contour of the part changes abruptly, as shown in Figure 5. This will help hide any sinks opposite bosses present.

The mineral filled nylon, as is indicated in Table 2, gives the least sink opposite mounting bosses of the reinforced thermoplastic materials.

Another method of eliminating sinks opposite bosses in body panel applications where aesthetics are of prime concern is by means of add-on bosses. This type of separate boss could be fabricated from zinc die cast, steel, or plastic, such as shown in Figure 6. The bosses are then attached to the body panel by means of adhesives, sonic welding or metal fasteners.

A third method of minimizing sinks opposite mounting bosses is to core out or eliminate mass from the base of the boss as is shown in Figure 7.

In body panel applications, mechanical assembly to other parts is required. Screw and stud stripping torque performance for plastic body panel materials are listed in Table 3.

Proper pilot hole and boss diameters are important in order to obtain maximum torques with filled resins. The pilot hole is molded into the body panel parts. The pilot hole size should be maintained within a tolerance of $\pm$.001" for the best fastening properties. Boss diameter must be of the correct size.

Undersized boss diameters may crack or

TABLE 3 - Screw and Stud Stripping Torque Performance of Thermoplastic Body Panel Materials

Screw or Stud Size	Minimum Requirements In.-Lbs.	Polyester Premix In.-Lbs.	Fiberglass Reinforced Nylon In.-Lbs.	Fiberglass Reinforced Thermoplastic Polyester In.-Lbs.	Mineral Reinforced Nylon In.-Lbs.
No. 8-18 Hi-Lo Shank	25	25	40- 45	40- 45	35- 45
1/4" - 20 Hi-Lo Shank	80	80-100	90-120	100-140	100-120
9/32 - 16 Hi-Lo Shank	80	100-150	90-120	105-140	80-110

break during driving or torqueing. Oversized bosses will add weight, increase surface sinks opposite bosses, and increase molding cycles.

Reinforced nylons and thermoplastic polyesters are all prone to warpage as molded. Mineral filled nylon gives the least warpage, and glass filled polyester causes the greatest problems. Warpage may be prevented by selecting the best gate location and correct gate size. Parts should be as uniform in wall thickness as is possible by design. Generous radii should be provided in all sharp corners to minimize differential shrinkage problems. Incorrect processing of filled thermoplastic resins such as improper mold temperatures, may also lead to warpage problems. Correct pressures in molding are also required to mold quality, defect free parts.

PAINTABILITY OF BODY PANEL MATERIALS

Paintability of glass filled nylon, thermoplastic polyester, and mineral filled nylon is an important factor in body panel applications. The finished painted surface of the thermoplastic body panels must match the finish of the adjacent sheet metal body parts. With proper mold finish and molding conditions, each of these three materials will give excellent surface finish and defect free parts as molded.

The filled nylons and thermoplastic polyesters require special primer systems so that paint adhesion may be obtained to the substrate materials. These primers are formulated to accept thermoplastic acrylic topcoat lacquers used on all General Motors automotive sheet metal. The primer-topcoat systems undergo certain performance testing before approved for production use. Laboratory paint system test requirements are listed in Table 4.

With the proper primers and processing, car color painted glass filled nylon, mineral filled nylon, and glass filled thermoplastic polyester have passed all of the required laboratory tests. Excellent paint adhesion and durability performance comparable to steel have also been obtained after hundreds of thousands of miles of service testing on test cars and one year exposures of painted panels in Florida and Arizona.

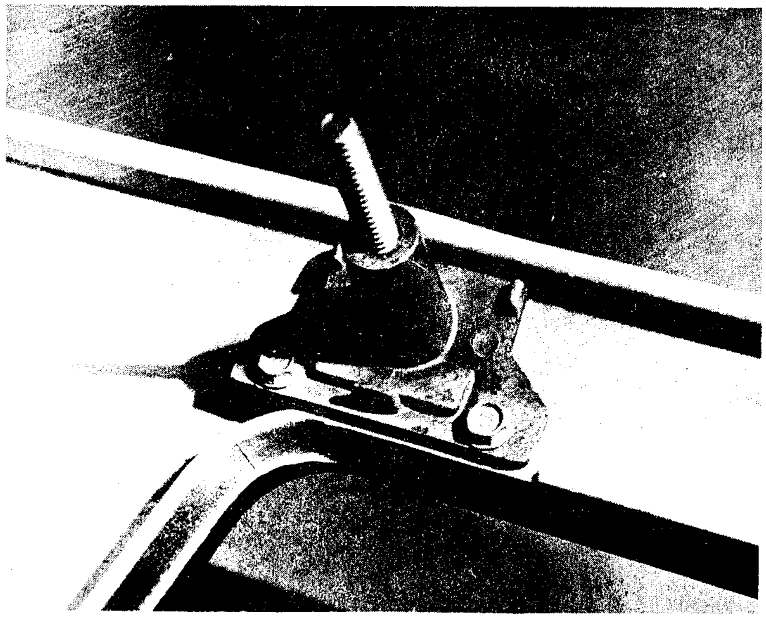

FIG. 6 - Separate metal mounting bosses attached to reinforced thermoplastic panels by screws give no sink opposite bosses.

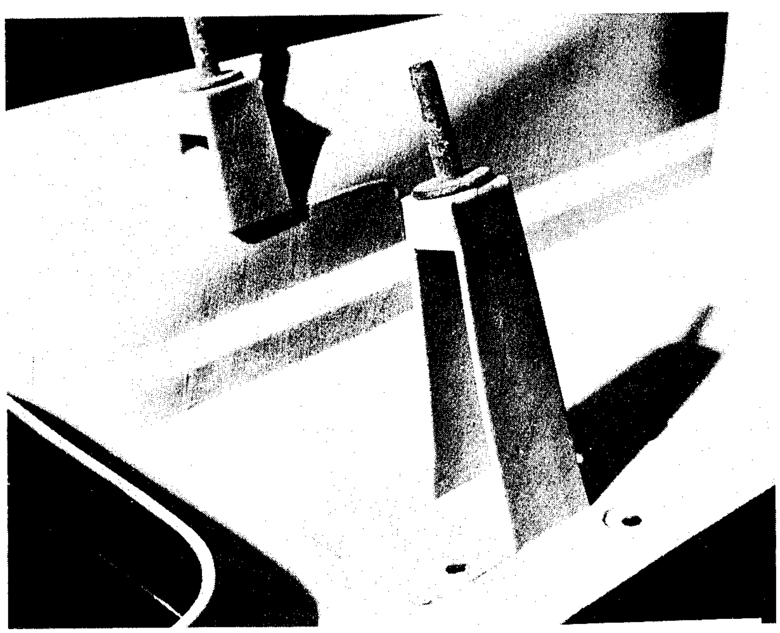

FIG. 7 - Coring on the 1974 Chevrolet Chevelle-Laguna rear panel to eliminate sinks opposite bosses.

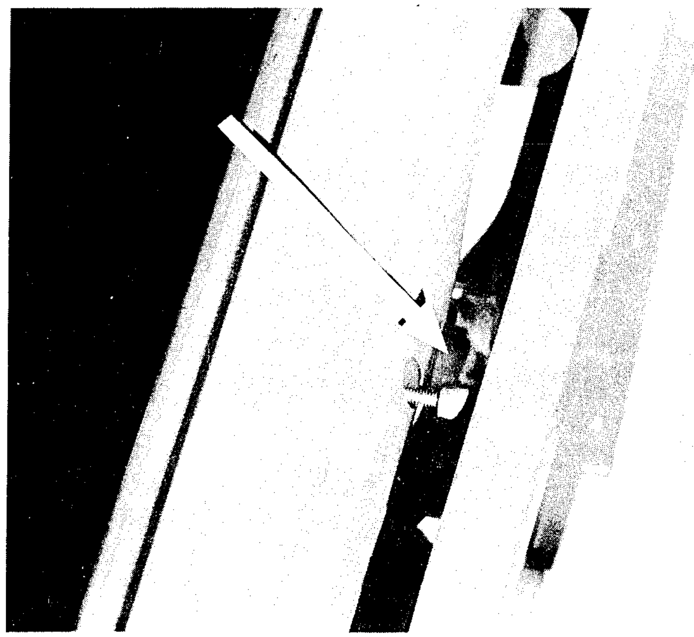

FIG. 8 - Mounting of prime-painted reinforced thermoplastic body panels to steel body. Body and primed panel have been painted car color in the positions indicated and processed through 300-350°F paint bake ovens. The plastic part on the right is supported loosely at the studs and bosses (arrow) and permitted to float in elongated holes in the rear body sheet metal panel on the left in the paint bake ovens.

TABLE 4 - Paint System Test Requirements for Thermoplastic Body Panels

Type of Test	Test Procedure	Test Description	Test Result Requirements
96 hours humidity	GM-4465-P	100% R. H. at 100°F	No loss of adhesion
2 hours water immersion	GM-4466-P	Water immersion at 100°F	No loss of adhesion
336 hours salt mist	GM-4298-D	Neutral salt spray test at 95°F - 100°F	No loss of adhesion
Gravelometer	SAE J400 at 0°F	Chip resistance of coating	Fair rating - 7 minimum on 10 scale
Tape adhesion	GM-9071-P	---	No loss of adhesion

In the paint processing of plastic body panels, certain requirements are necessary to obtain quality painted parts. Paint racking of plastic body panels is a very important factor. The plastic body panels have a much higher coefficient of thermal expansion than steel. When the parts are exposed to oven paint bake temperatures of up to 350°F, the reinforced thermoplastic panels expand up to .5 inch in length greater than steel on an across-car panel and may permanently warp or distort if attached firmly to the steel body. To prevent this warpage, the part must be racked in a manner so that it is free to float on the paint rack. This type of floating paint racking is shown in Figure 8.

The filled nylon and thermoplastic polyesters are able to withstand prime bake oven temperatures of 300°F and topcoat and reflow temperatures of 350°F for one hour. The time in the paint bake ovens should be minimized for reinforced nylon materials. Over exposure to bake oven temperatures may cause filled nylon materials to degrade. The filled thermoplastic polyester resin will not degrade at extended exposures to paint oven temperatures because of better heat stability.

SUMMARY

1. Guide Lamp has invested years of materials and product development and has had extensive previous production experience with reinforced thermoplastics. This background was necessary to extend reinforced thermoplastic materials usage for the first time into rigid exterior body panel applications that are painted car color.

2. The specific strength and heat resistance of filled nylon and thermoplastic polyesters have enabled these resins to replace such materials as steel, zinc die cast, and sheet molding compound in body panel applications. Cost savings, weight reduction, and added corrosion resistance have been gained.

3. Mineral filled nylons have the least sink opposite bosses of the thermoplastic resins. Sinks may also be eliminated by means of add-on bosses or reduced by cored-out thick areas. Proper design is essential to obtain suitable

the least warpage as molded of the three reinforced thermoplastics discussed.

4. Glass filled nylon is the lowest cost and lowest specific gravity or weight material of the three materials in use.

5. Glass-filled thermoplastic polyester has the highest structural strength and rigidity of the materials reviewed.

6. Reinforced nylons and thermoplastic polyesters are painted with standard acrylic thermoplastic topcoats after priming. Proper primers and processing will give excellent paint adhesion and durability--equivalent to car color painted steel.

7. Proper part design is necessary to give successful filled thermoplastic polyester and nylon exterior body panels. These materials have been proven satisfactory by their successful use without any field service problems for 1973 or 1974 Chevelle, Cadillac, Oldsmobile, Buick and Pontiac car color, exterior body panels.

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